CpE 645 Image Processing and Computer Vision

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Image Perception

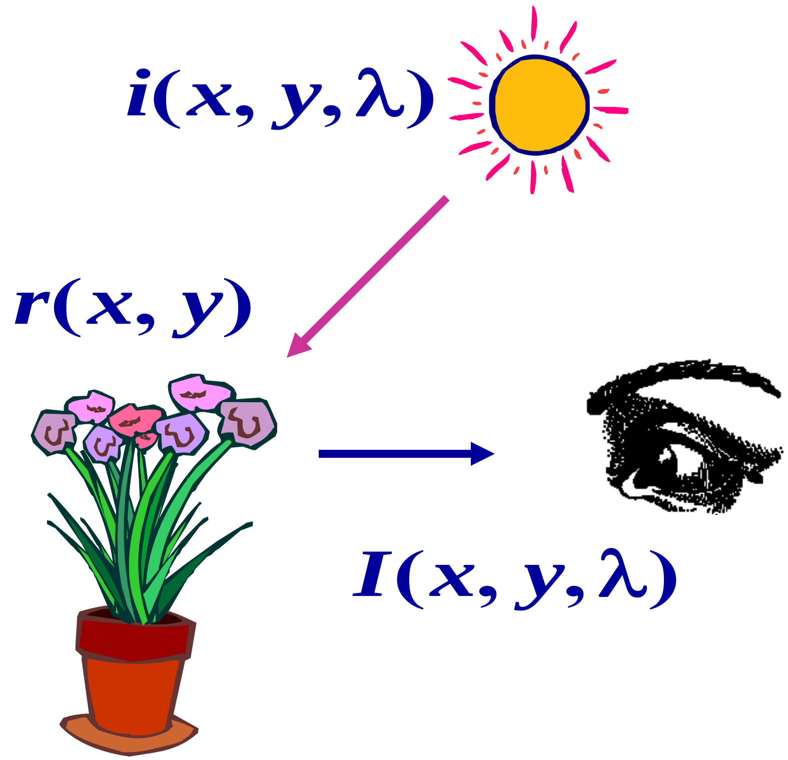
- Image perception involves three components:
  - Light source
  - Illumination (***i***)
  - Reflection (***r***)
- A simple perception model

$$\boldsymbol{I}(x, y, \lambda) = \boldsymbol{i}(x, y, \lambda) \cdot \boldsymbol{r}(x, y)$$

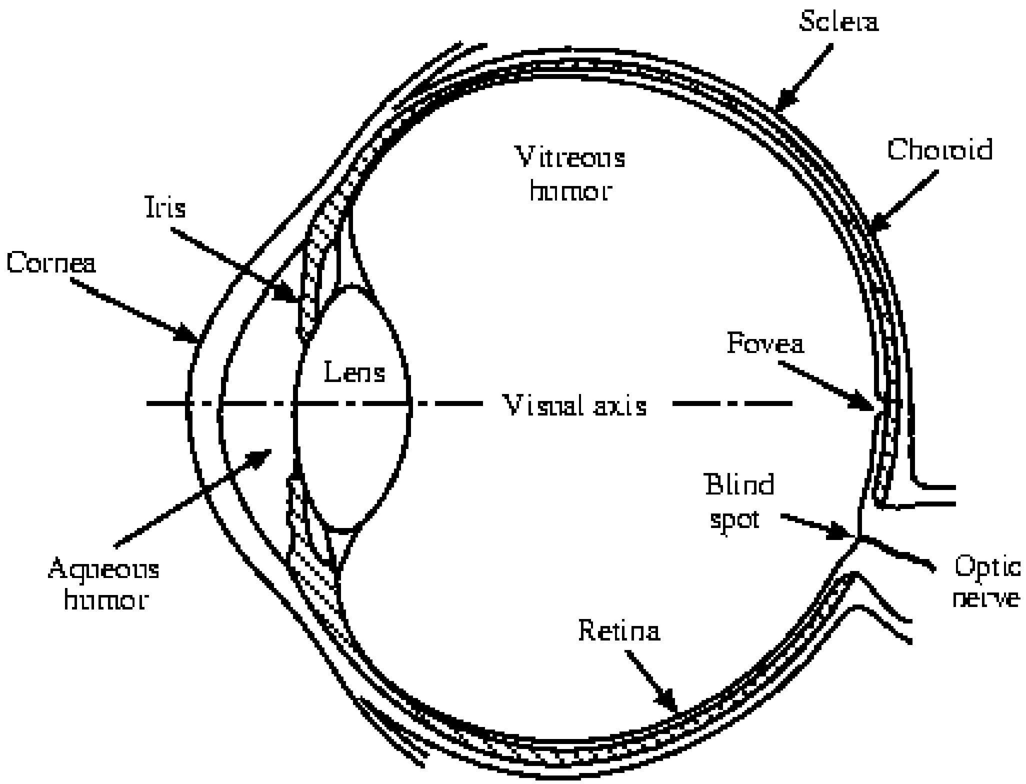
where

$$0 < \boldsymbol{i}(x, y, \lambda) < \infty$$

$$0 < \boldsymbol{r}(x, y) < 1$$

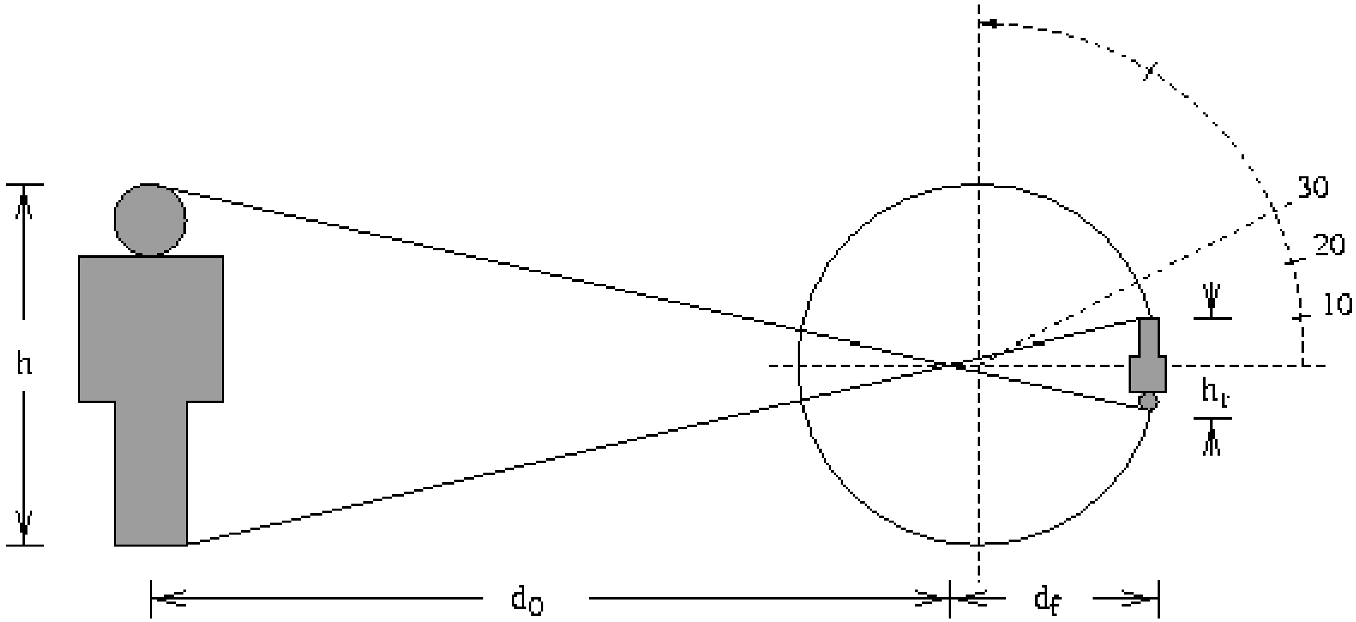


Human Visual System



The average eye is about 20mm in diameter

Human Visual System



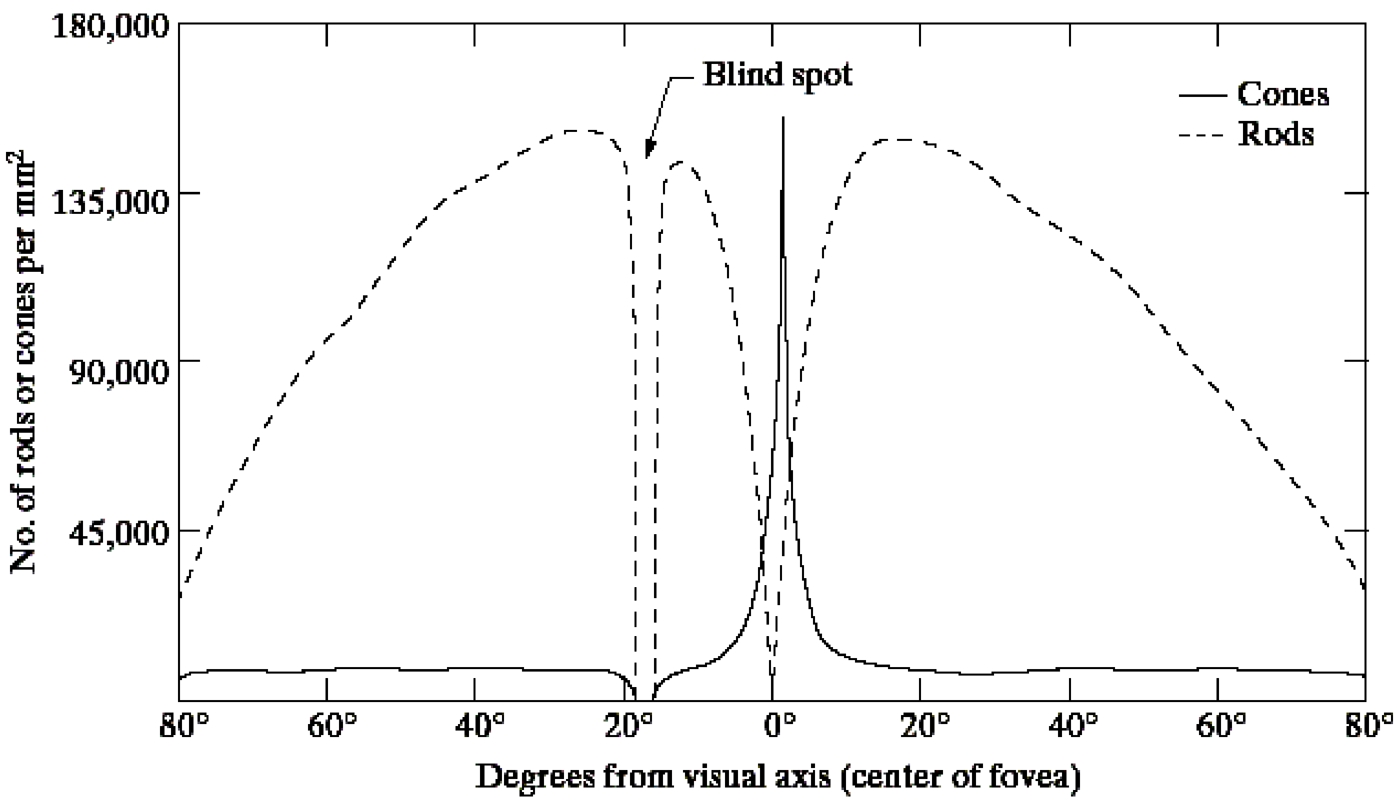
- The distance between the focal center of the lens and the retina d_f=14 ~ 17 mm
- The size of the object at retina is $h_r = \frac{d_f h}{d_o}$

  This size can also be represented by the angle on retina.

Human Visual System

- Retina contains two types of light receptors:
  - **Rods**: 100 million, thin-long, very sensitive, responsible for **scotopic** or low-light vision, distributed over a wide region on the retina
  - **Cones**: 7 million, thick-short, less sensitive, responsible for **photopic** vision or bright-light vision, also allow us to perceive color, concentrated around the Fovea
- The pupil of the eye acts as an aperture. In bright light (2mm in diameter), it acts as a low-pass filter (for green light) with a passband of about 60 cycles/degree.

Human Visual System



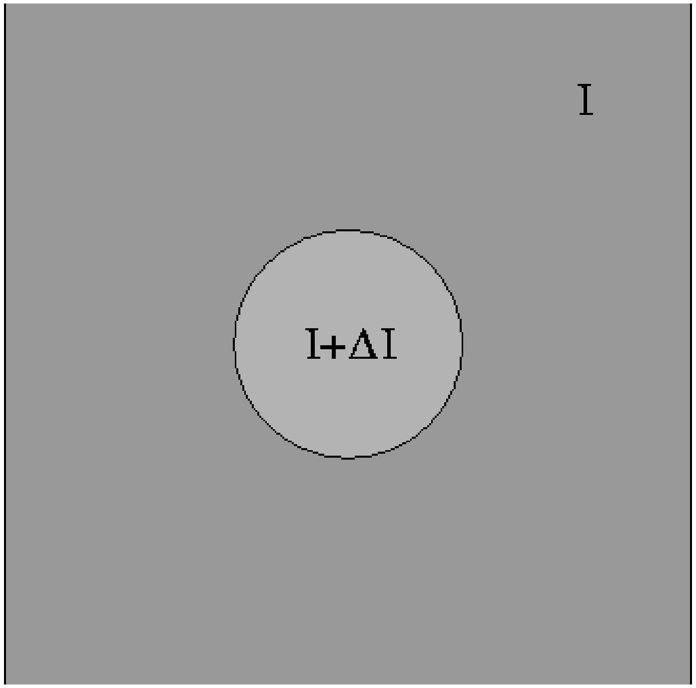
Distributions of rods and cones in the retina

Brightness and Contrast

- Brightness is a perceptual quantity of the intensity of a visual stimulus.
- Brightness is subjective, while intensity is objective.
- Brightness is closely related to intensity, but it is not proportional to intensity.
- The relationship between brightness and intensity can be derived from a set of experiments – Weber's.
  - Assume a spot (a small foreground region) is placed in a constant background.
  - Set the background intensity as $\mathbf{I}$
  - Set the foreground intensity as $\mathbf{I+\Delta I}$

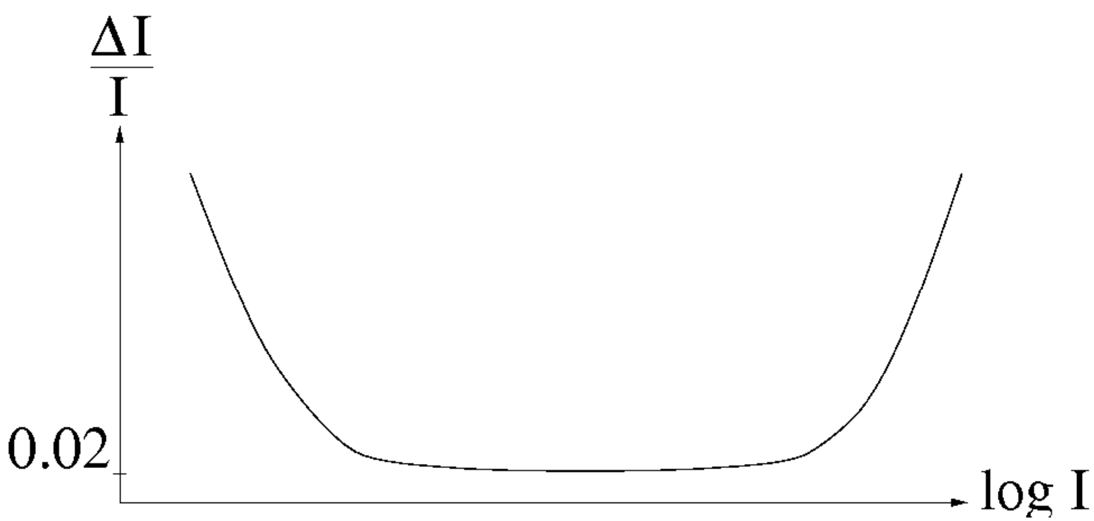
Brightness and Contrast

- Let $\Delta \mathbf{I}$ start at zero and increase slowly.
- The observer is asked to indicate when the spot on the constant background becomes visible (*just noticeable difference*).
- Record the pair of **(I, ΔI**)
- Repeated this procedure for different values of **I** over the full range.



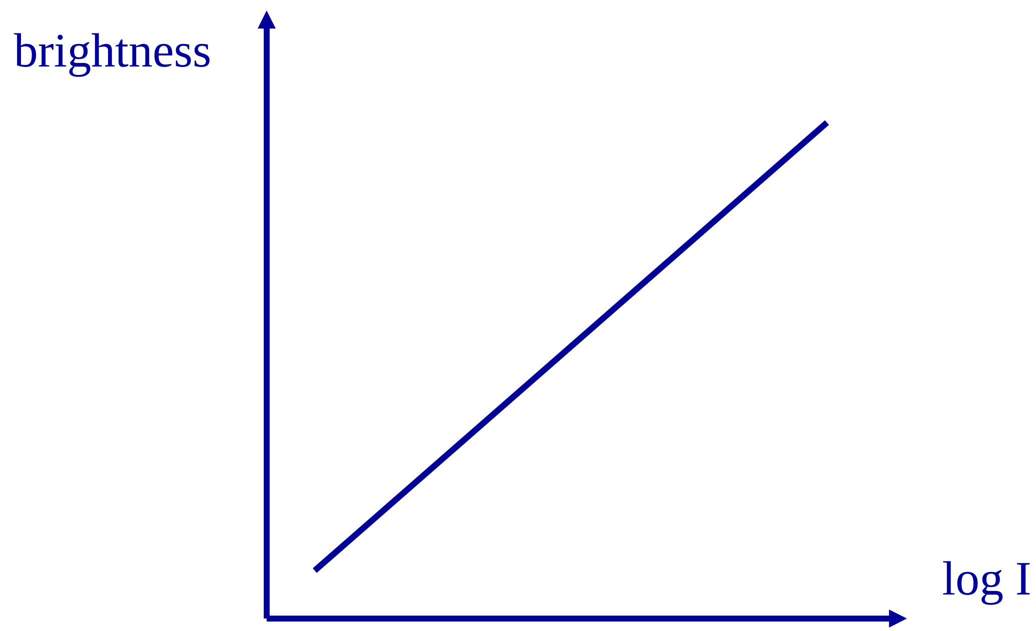
Brightness and Contrast

- For a large range of values I, the following relationship was observed: $$\frac{\Delta \mathbf{I}}{\mathbf{I}} \approx \textbf{const} \approx \mathbf{0.02}$$
- This relatively constant ratio is called the **Weber's ratio**.



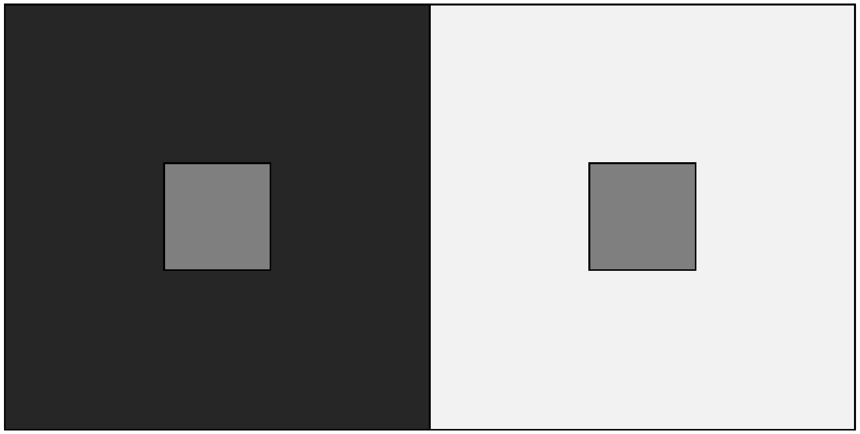
Brightness and Contrast

- It was also found that the subjective brightness is approximately a logarithmic function of the intensity.

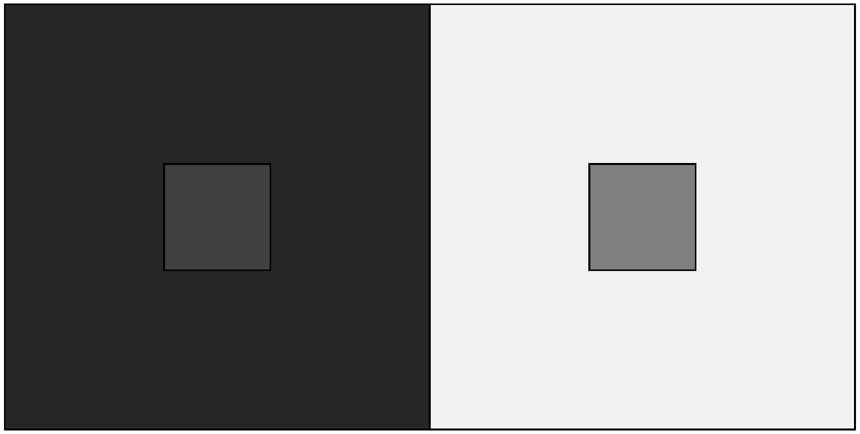


Brightness and Contrast

- Weber's ratio suggests that our brightness perception is closely related to the contrast.
- In figure (a) the center blocks have the same intensity value but appear differently in brightness; In figure (b) the center blocks have different values but appear similarly in intensity.



(a)



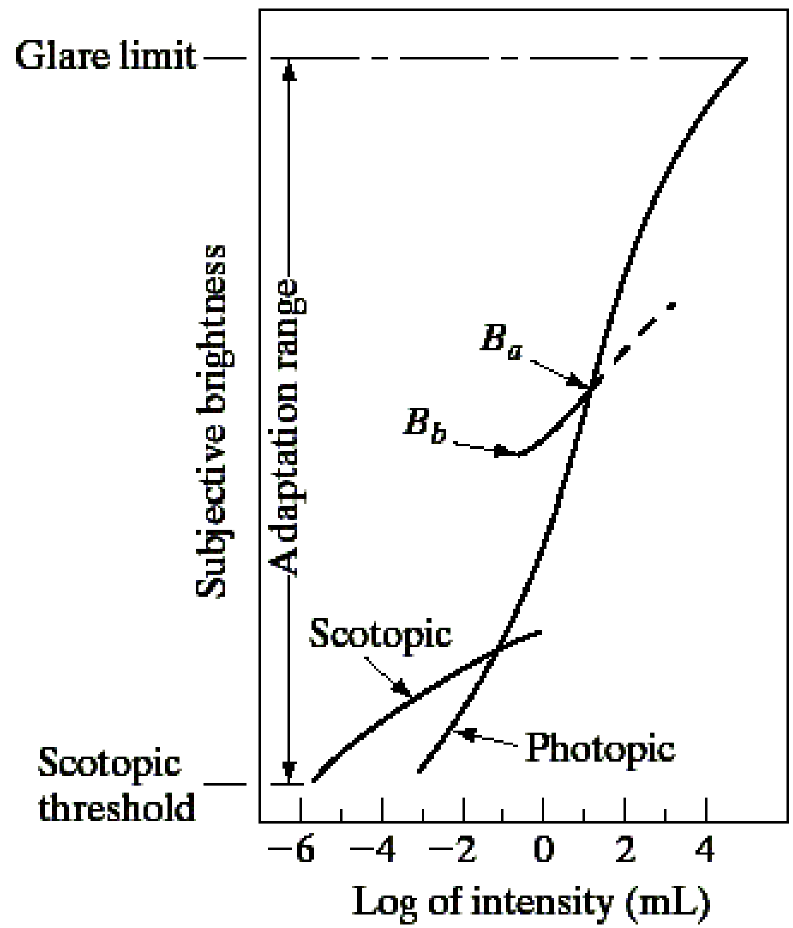
(b)

Brightness and Contrast

- Weber's ratio also implies that we are better able to notice differences in intensity when the image is dark than when it is light.
- For a normalized intensity range from **0** (darkest) to **1** (brightest), Weber's ratio of **0.2** in contrast suggests that we can only resolve **50** gray levels in a monochrome image.
- In fact under a typical viewing condition, we can usually distinguish 60~100 gray levels, which is roughly consistent with Weber's ratio.

Brightness and Contrast

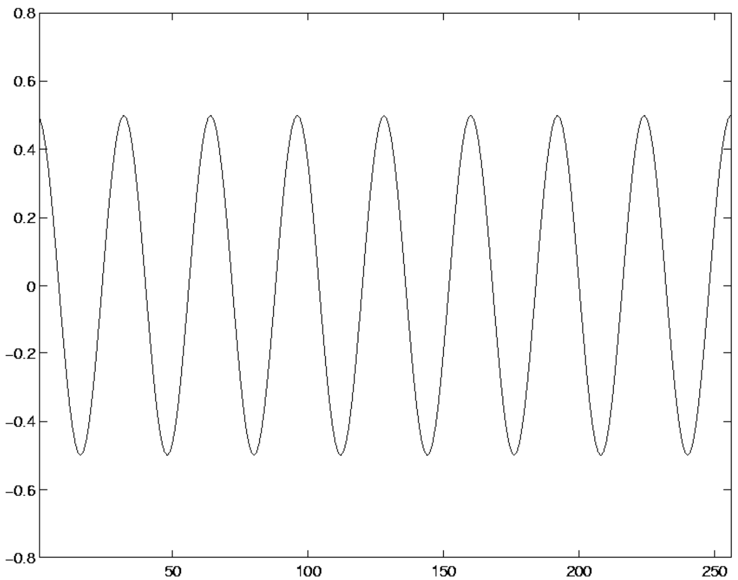
- The dynamic range of HVS is enormous - on the order of 10^{10}- from the **scotopic threshold** to the **glare limit**
- HVS can not operate over the entire the range simultaneously. It accomplishes large variations due to ***brightness adaptation***

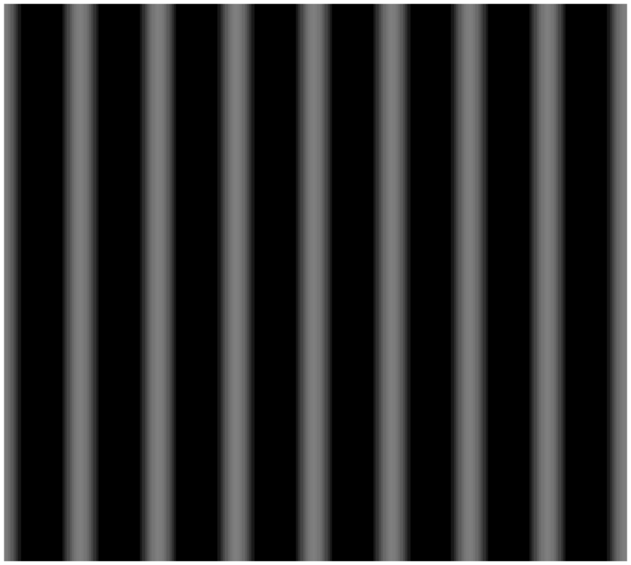


Spatial Frequency

- A 256x256 image with single spatial frequency of 1/32 cycles/sample (or 2π/32 rad/sample).

$$x[n_1] = 0.5\cos\left(\frac{n_1 \cdot 2\pi}{32}\right), \quad x[n_2] = 1, \quad x[n_1, n_2] = x[n_1] \cdot x[n_2].$$

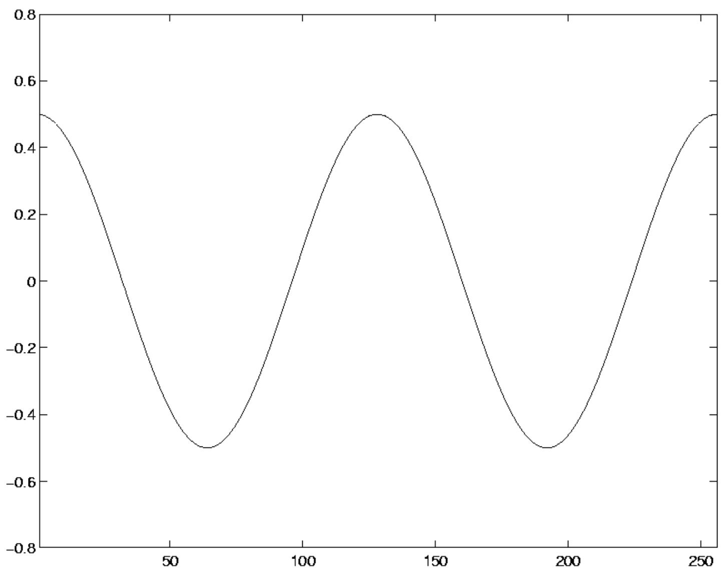




Spatial Frequency

- A 256x256 image with single spatial frequency of 1/128 cycles/sample (or 2π/128 rad/sample).

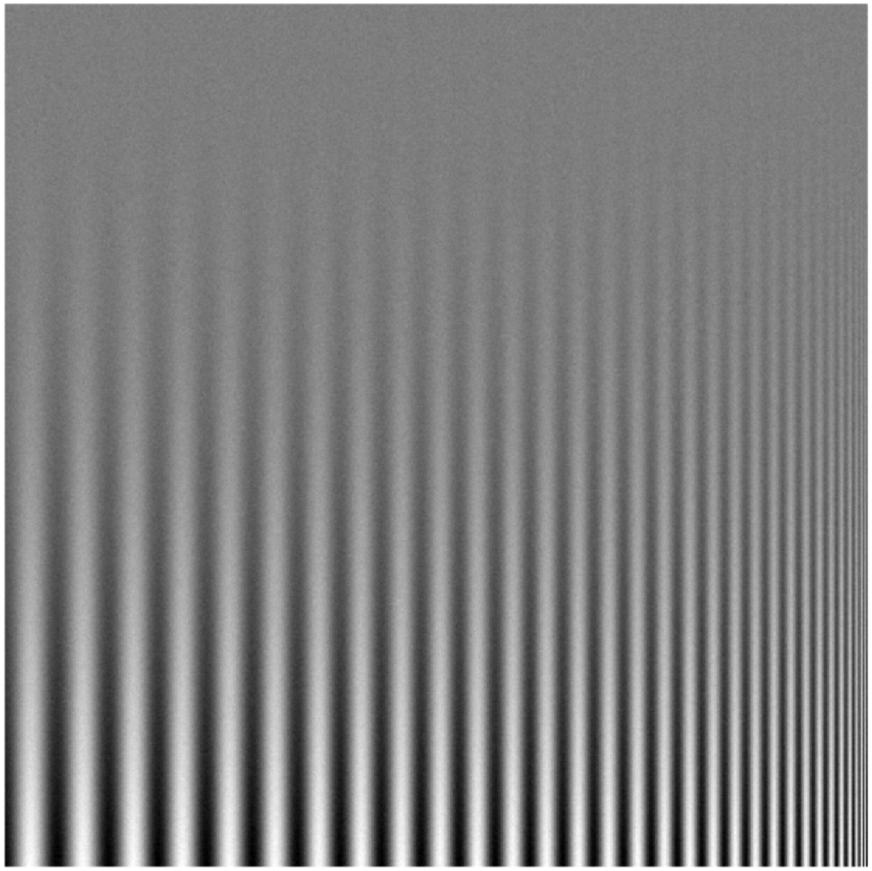
$$x[n_1] = 0.5\cos\left(\frac{n_1 \cdot 2\pi}{128}\right), \quad x[n_2] = 1, \quad x[n_1, n_2] = x[n_1] \cdot x[n_2].$$

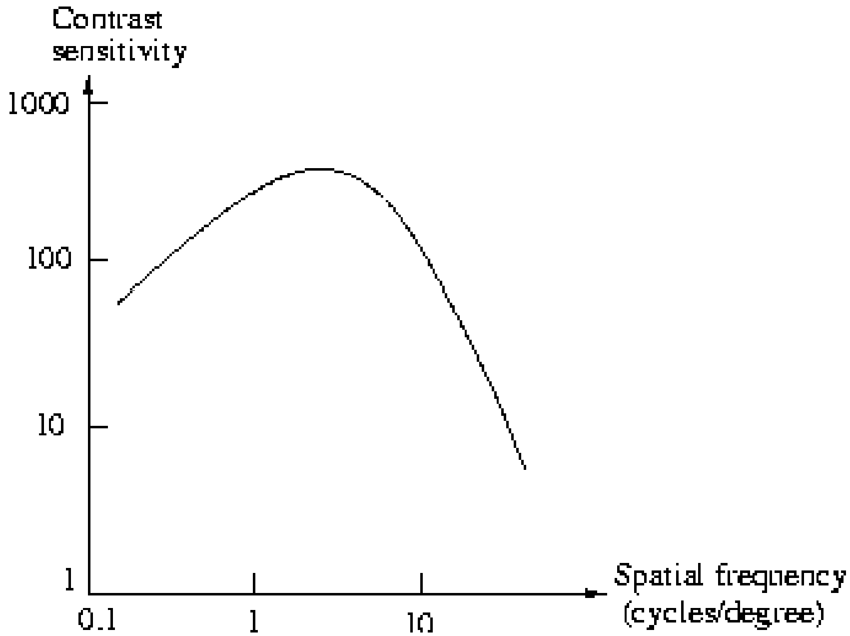


Spatial Frequency Properties of HVS

- Human eye is more sensitive to some spatial frequencies than to others.
  - In particular, we are more sensitive to spatial frequencies in the range of **3~10 cycles per degree** of retina arc. (see slide 4 for converting spatial distance to angle on retina arc.)
  - We are less sensitive to very high frequencies.

Spatial Frequency Properties of HVS

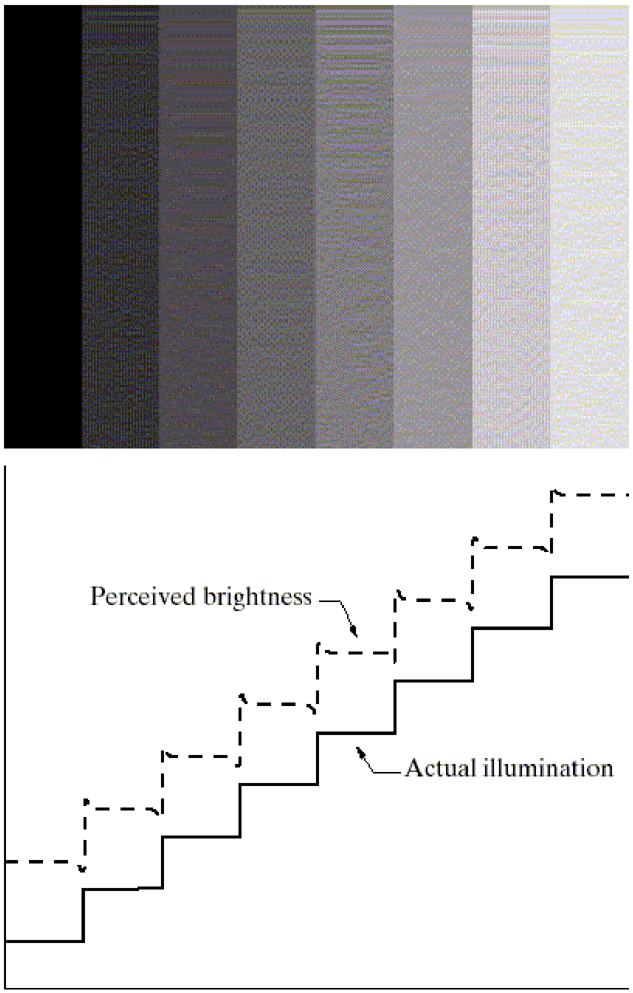


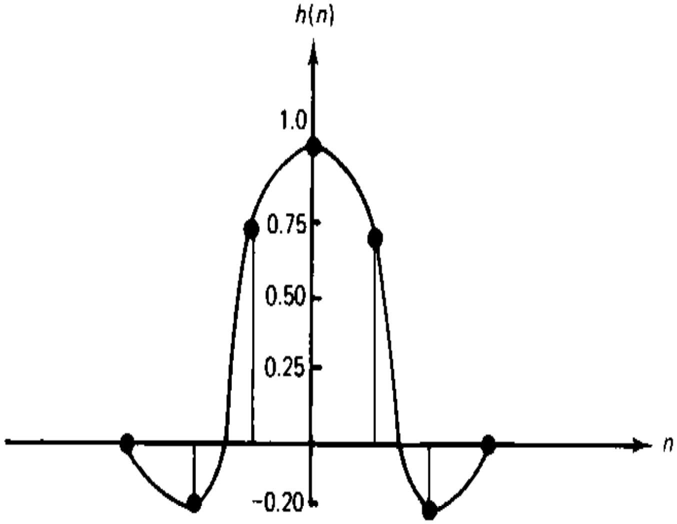


Spatial Frequency Properties of HVS

- Consider a dark region next to a bright region,
  - Although the shades are constant, we can observe overshoot and undershoot near the transition boundary, i.e. the dark region looks darker and the bright region looks brighter.
- The overshoot and undershoot is associated with visual phenomenon known as **lateral inhibition**
- Based on this observation, we might describe the behavior of the HVS as being a lowpass filter.

Spatial Frequency Properties of HVS





(c) Nature of the visual system impulse response.

Temporal Properties of HVS

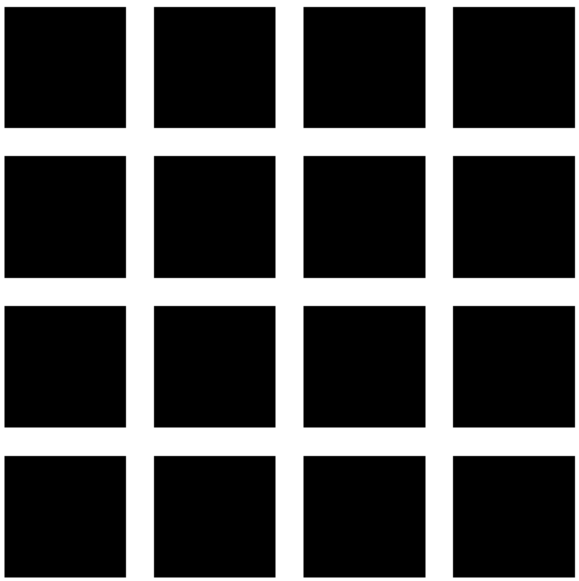
- **Critical duration (Block's law):**
  - For average illumination conditions, two energy normalized flashes are indistinguishable in duration if the durations are less than about 30 ms.
  - This duration changes with average illumination. In low-light illumination situations, it becomes greater than 30ms.

Temporal Properties of HVS

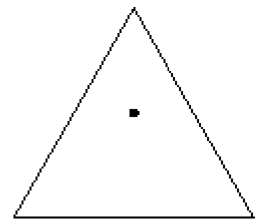
- **Critical fusion frequency:**
  - If a light source flashes at a frequency that is higher than the critical fusion frequency, it will appear as a constant light with the same average intensity. This critical fusion frequency is about 50 to 60Hz.
  - Example: Interlaced television picture fields are flashed at 60Hz.

Optical Illusion

Here are some examples of optical illusion.

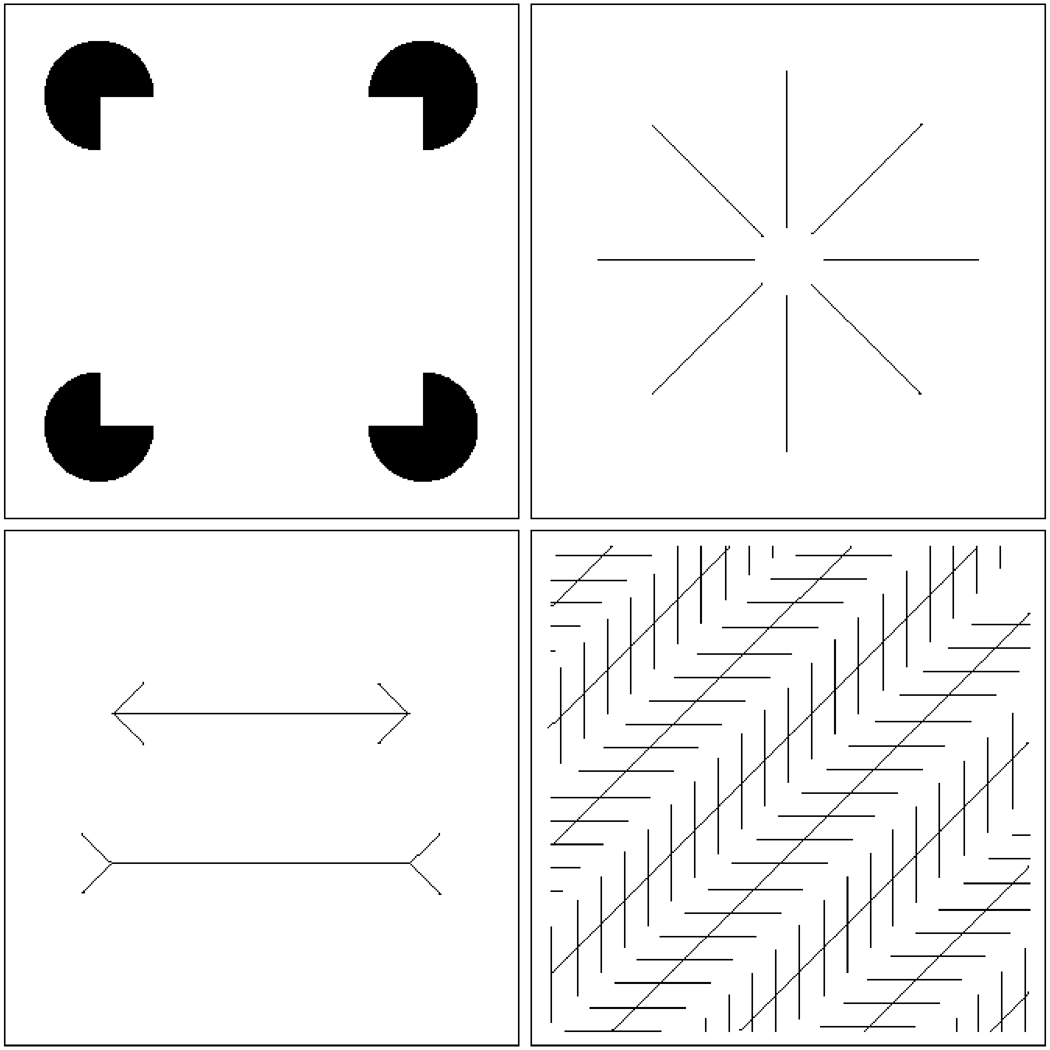


(a)

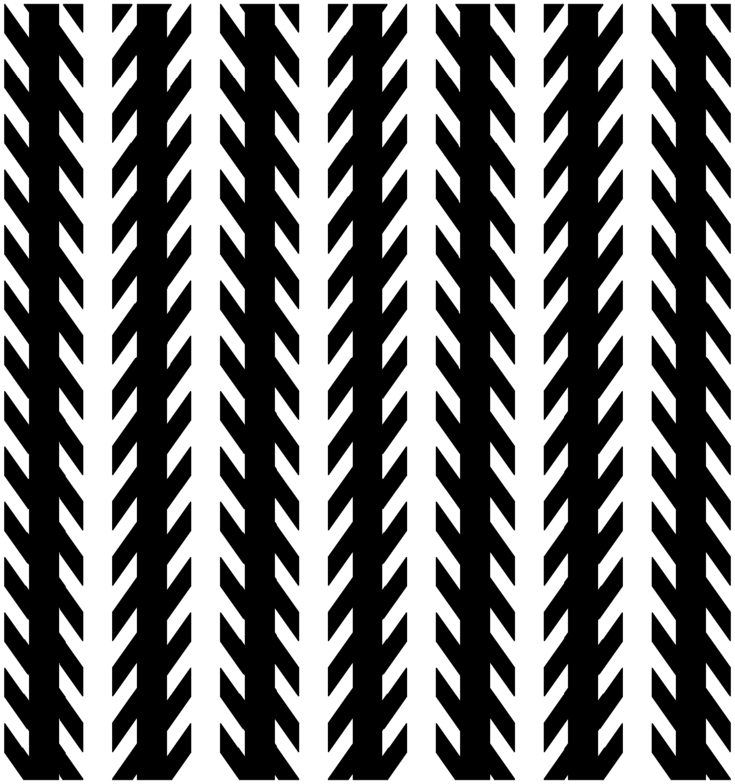


(b)

Optical Illusion



Optical Illusion



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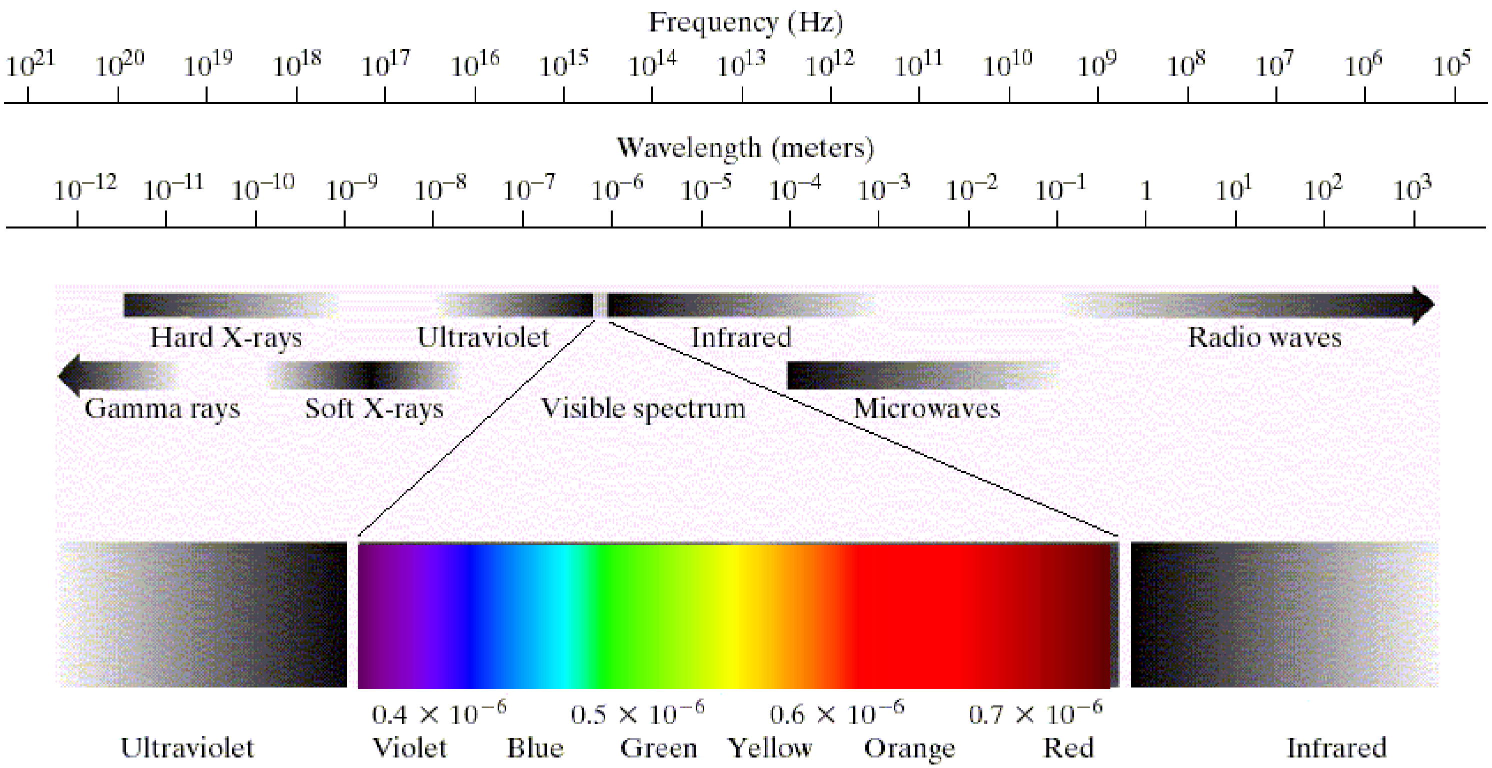
Color Representation

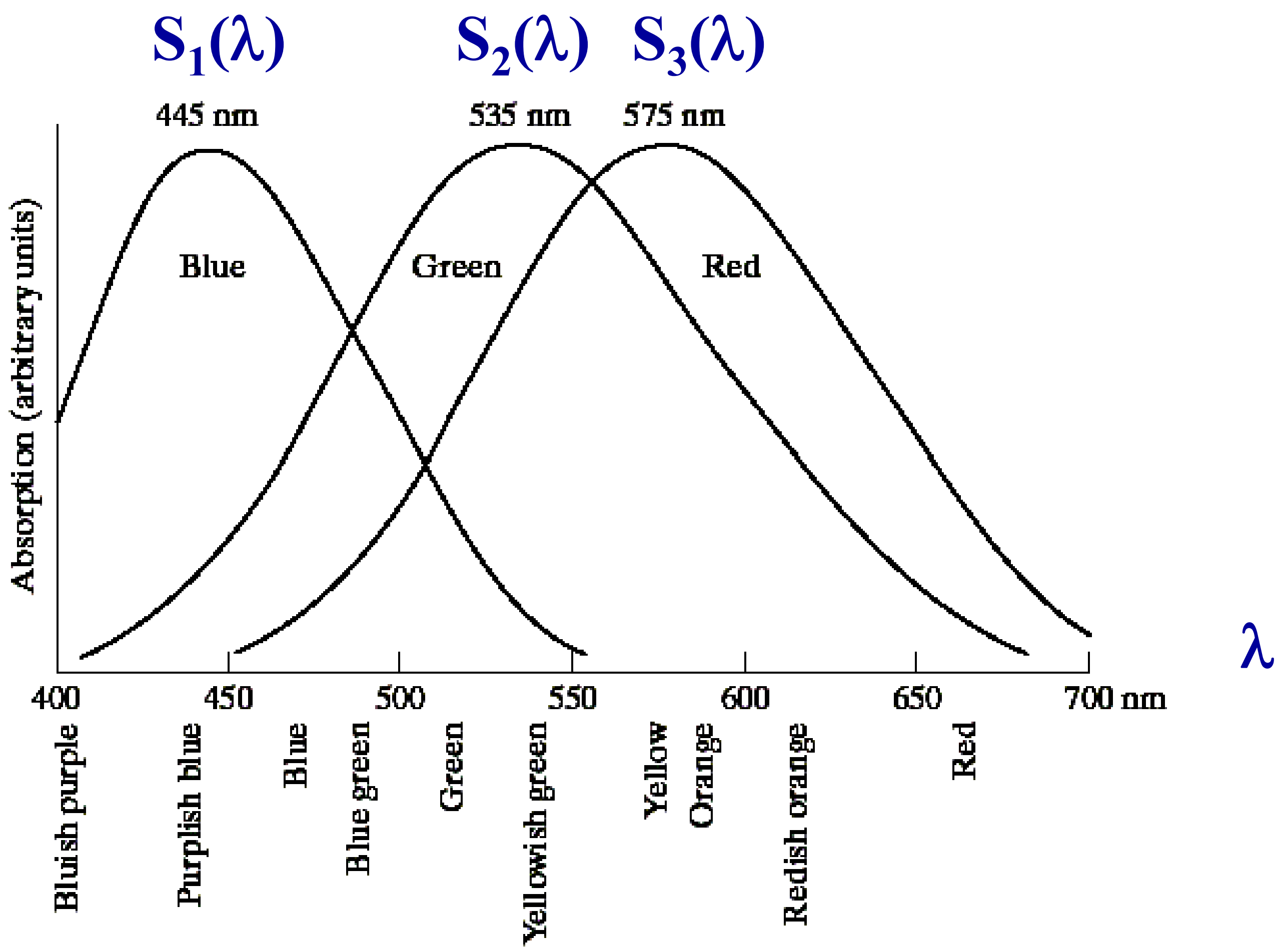
- Retinal photoreceptors only respond to electromagnetic wavelength in the range from 350 ~ 780 nanometer



Color Representation

- Although we are only able to distinguish among 100 gray levels for monochrome images, HVS is able to discern 1000 of colors.
- When the distribution of energy in the beam of light is not effectively uniform across the spectrum, the light appears colored.
- In HVS, color is perceived by three different types of cones, each of which has a different peak absorption characteristic.

Color Representation



Color Representation

- The spectral energy distribution of a color light $C(\lambda)$ will produce a color sensation that can be described by spectral responses as

$$\alpha_i(C) = \int_{\lambda_{min}}^{\lambda_{max}} S_i(\lambda)\, C(\lambda)\, d\lambda, \quad i = 1, 2, 3$$

- The implication of this model is interesting: two colors $C_1(\lambda)$ and $C_2(\lambda)$ are two spectral distributions that produce responses $\alpha_i(C_1)$ and $\alpha_i(C_2)$ such that

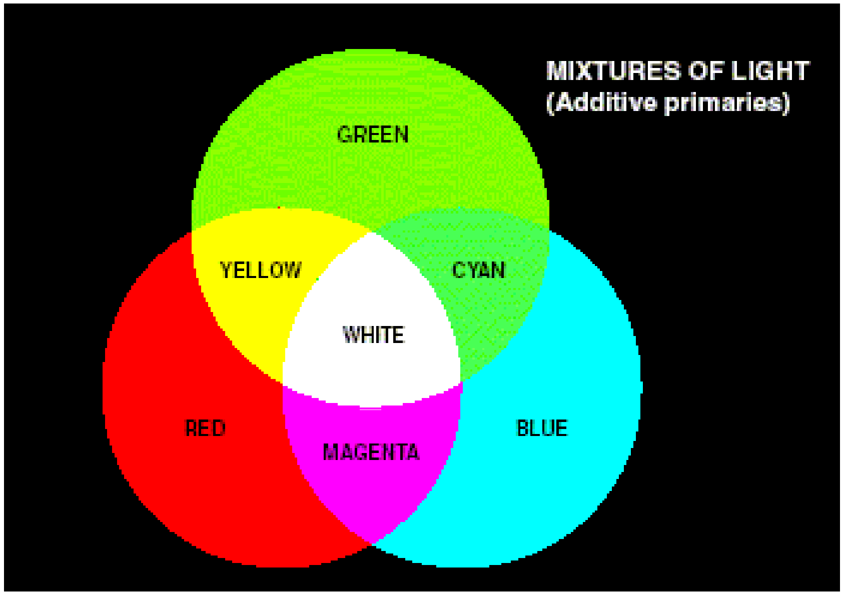
$$\alpha_i(C_1) = \alpha_i(C_2), \quad i = 1, 2, 3,$$

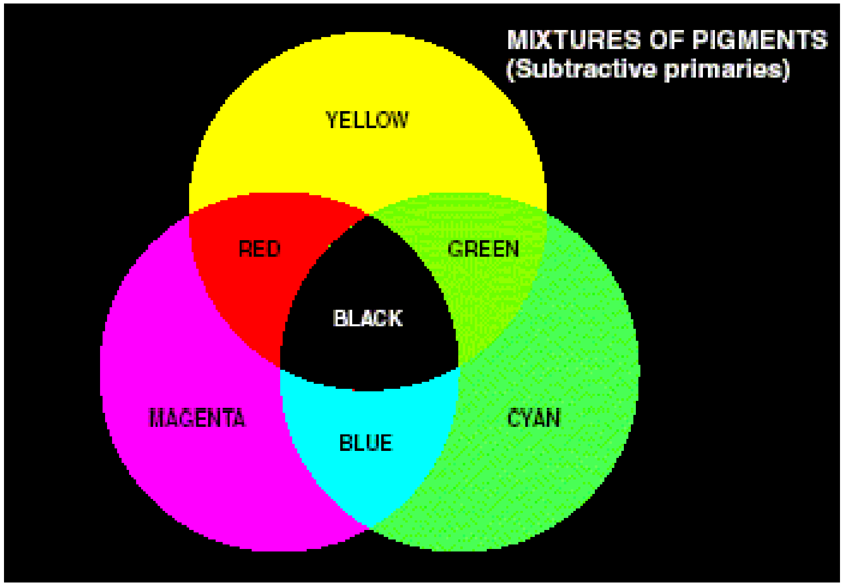
then the colors are perceived to be identical.
- The two colors that look the same could have different spectral distributions.

Color Representation

- In the early 1800s Thomas Young showed that a broad range of colors could be generated by mixing three beams of light provided that their frequencies are widely superadded.
- When three such beams combine to produce white light they are called **primary colors**.
- Primary color set is not unique.
- A wide range of colors can be created by mixing red (**R**), green (**G**), and blue (**B**), this primary color set tends to be used more frequently.

Color Representation





Additive color system

Substractive color system

Color Representation

- Additive color system can be used to generate new colors from the three primaries.
  - Any two colors that together produce white are said to be **complementary**.
  - Used in image display.
- Substractive color system can be used to represent a phenomenon called selective or preferential absorption.
  - The great majority of objects in nature appear to have characteristic colors as a result of preferential absorption of some pigment molecules.
  - Used in image printing.

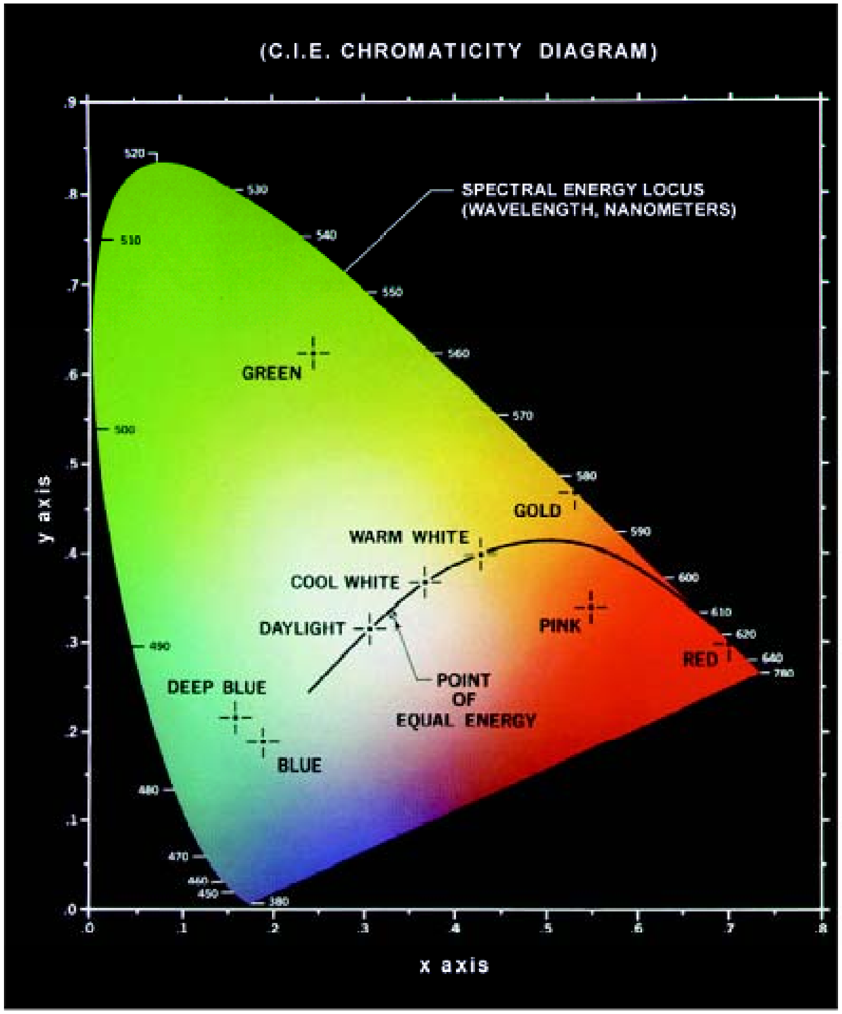
Color Representation

- The amount of red, green, and blue needed to form any particular color are called the tristimulus values, and are denoted as ***X***, ***Y***, ***Z***.
- A color is then specified by its trichromatic coefficients

$$x = \frac{X}{X+Y+Z},\ y = \frac{Y}{X+Y+Z},\ z = \frac{Z}{X+Y+Z}.$$

- It is always held that $x + y + z = 1$, or $z = 1 - (x + y)$.
- Given any pair of ***x*** (red) and ***y*** (green), then ***z*** (blue) value is fixed, one can find the corresponding color in the CIE chromaticity diagram.
- All pure colors lie on the tongue-shape boundary of the chromaticity diagram.

Color Representation



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Color Space

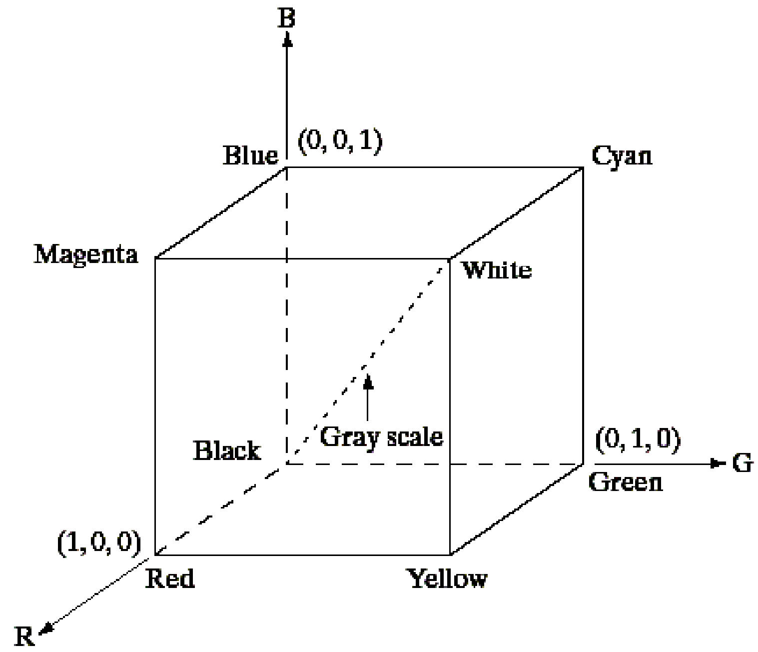
- Red, green, and blue are designated primary colors by the CIE (Commission Internationale de l'Eclairage)
  - R = 700 nm,

    G = 546.1 nm and

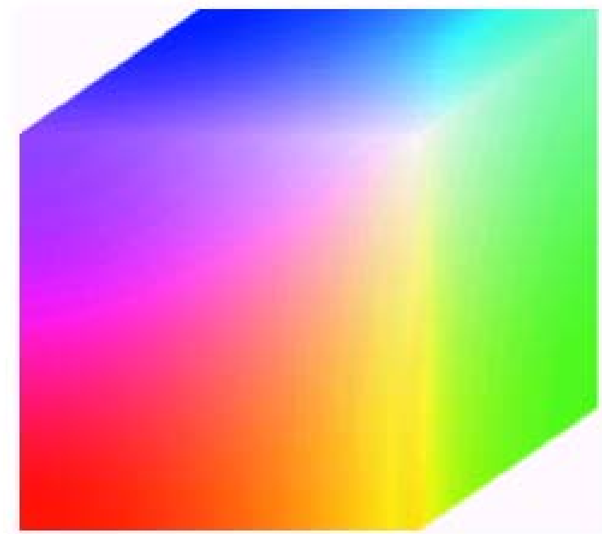
    B = 435.8 nm
  - Reference white is

    R = G = B = 1, which

    has a flat spectrum.



Color Space



RGB 24–bit Color Space

Color Space

- NTSC (National Television Systems Committee) transmission system (Y,I,Q)

$$\begin{bmatrix} Y \\ I \\ Q \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ 0.596 & -0.274 & -0.322 \\ 0.211 & -0.523 & 0.312 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- This color space was developed to facilitate transmission of color images using the existing monochrome TV channels without increasing the bandwidth requirement
- It has been used for analogue television broadcasting in America.

Color Space

- ITU (International Telecommunication Union) recommendation 601-1(ITU-T.BT 601-1)

$$\begin{bmatrix} Y \\ C_b \\ C_r \end{bmatrix} = \begin{bmatrix} 0.299 & 0.587 & 0.114 \\ -0.169 & -0.331 & 0.500 \\ 0.500 & -0.419 & 0.081 \end{bmatrix} \begin{bmatrix} R \\ G \\ B \end{bmatrix}$$

- This is the international standard for digital coding of TV pictures at 525 and 625 line rate. It is also used in the JPEG image coding standard.

Color Space

- HIS (hue, saturation, intensity)

$$H = \begin{cases} \theta & \text{if } B \le G \\ 360^o - \theta & \text{if } B \ge G \end{cases} \quad \text{where}$$

$$\theta = \cos^{-1}\left\{ \frac{\frac{1}{2}[(R-G)+(R-B)]}{[(R-G)^2 + (R-B)(G-B)]^{1/2}} \right\}.$$

$$S = 1 - \frac{3}{(R+G+B)}[\min(R,G,B)].$$

$$I = \frac{1}{3}(R+G+B).$$

- Used in machine vision, and image processing applications.

Color Space

- HIS perception:
  – Intensity: light brightness

    50 150

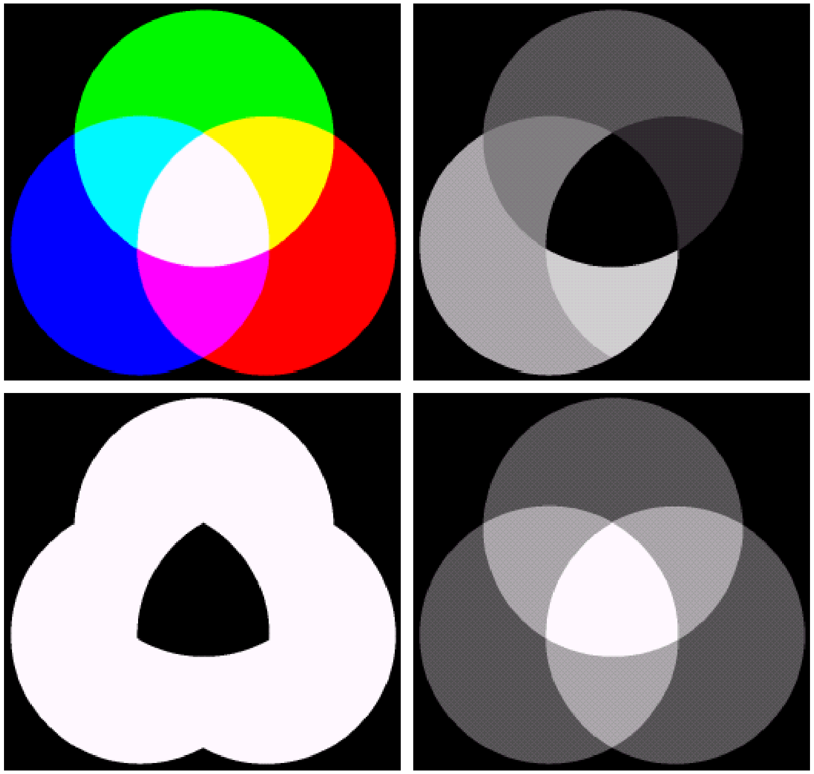
  – Hue: color wavelength (in *nm*)

    175 0

  – Saturation: color strength (pureness)

    150 255

Color Space



a b
c d

FIGURE 6.16 (a) RGB image and the components of its corresponding HSI image: (b) hue, (c) saturation, and (d) intensity.